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Effect of Composite Substrates on the Mechanical Behavior of Brazed Joints in Metal-Composite System

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Abstract

Advanced composite components are being considered for a wide variety of demanding applications in aerospace, space exploration, and ground based systems. A number of these applications require robust integration technologies to join dissimilar materials (metal-composites) into complex structural components. In this study, three types of composites (C-C, C-SiC, and SiC-SiC) were vacuum brazed to commercially pure Ti using the active metal braze alloy Cusil-ABA (63Ag-35.3Cu-1.75Ti). Composite substrates with as fabricated and polished surfaces were used for brazing. The microstructure and composition of the joint, examined using scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS), showed sound metallurgical bonding in all systems. The butt strap tensile (BST) test was performed on bonded specimens at room and elevated temperatures. Effect of substrate composition, interlaminar properties, and surface roughness on the mechanical properties and failure behavior of joints will be discussed.

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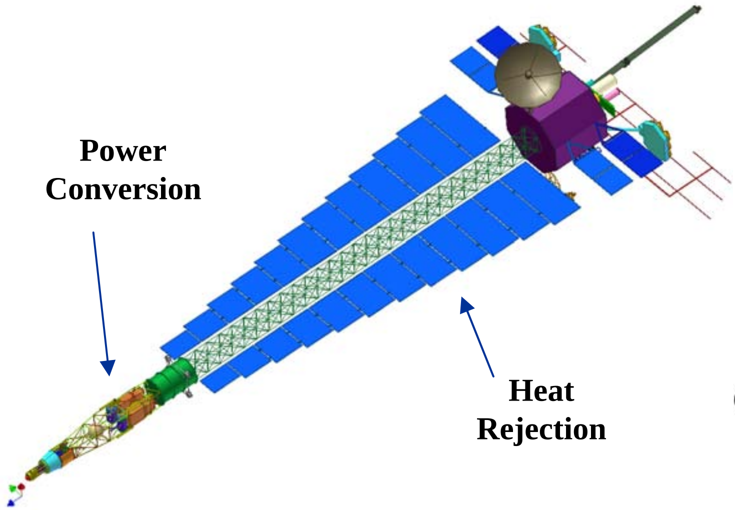
Outline

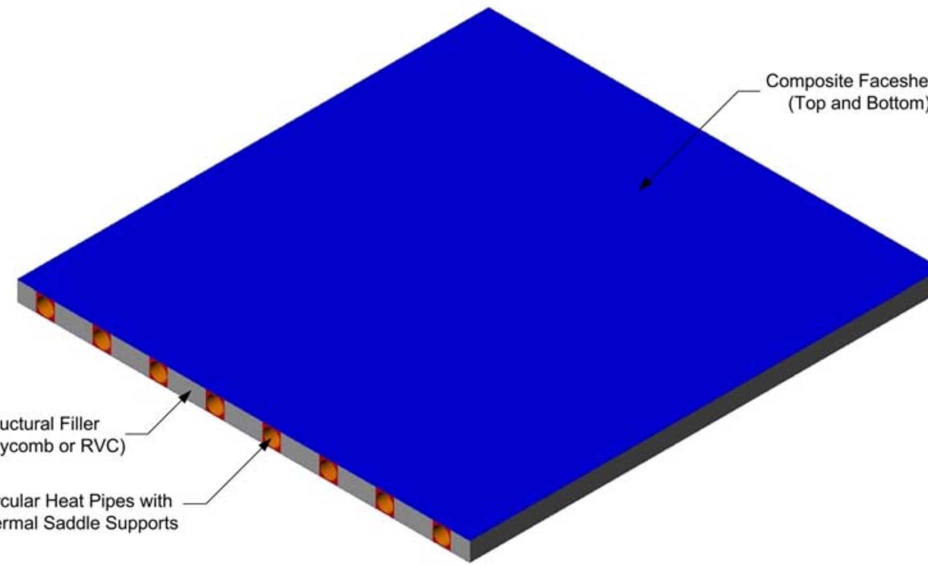
- **Introduction -** ***Need for Joining and Integration Technologies***
- **Challenges in Bonding of Metal-Composite System**
    - ***Thermal Expansion Mismatch***
    - ***Joint Design and Testing***
- **Brazing of Titanium to Composites** ***(C/C, C/SiC, SiC/SiC)***
    - ***Microstructural Analysis***
    - ***Mechanical Behavior***
        - ***Microhardness Behavior***
        - ***Butt Strap Tensile (BST) Tests***
    - ***Effect of Surface Roughness***
- **Summary and Conclusions**

Need for Joining and Integration Technologies

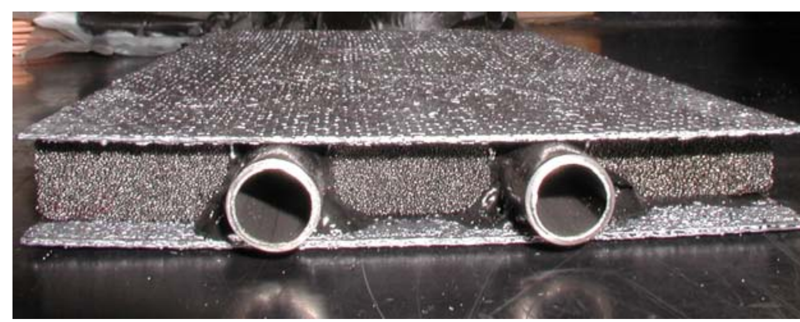
- **Joining and integration technologies are key to development and utilization of advanced composites in aerospace and ground based applications.**
  - **Aerospace Systems**
    - ***Aerospace and Space Propulsion Components (Combustor Liners, Exhaust Nozzles, Nozzle Ramps, Turbopump Blisks)***
    - ***Thermal management systems (Radiators, recuperators), optical components, and dimensionally stable space structures***
  - **Ground Based Systems**
    - ***Nuclear Industries, Land Based Power Generation, Process Industries, Heat Exchangers, Recuperators, Microelectronic Industries (Diffusion Furniture, Boats)***
- **The development of robust joining and assembly capability will allow the application of advanced composites technology in a timely manner.**

Joining and Integration Technologies are Key to Manufacturing of Heat Rejection System



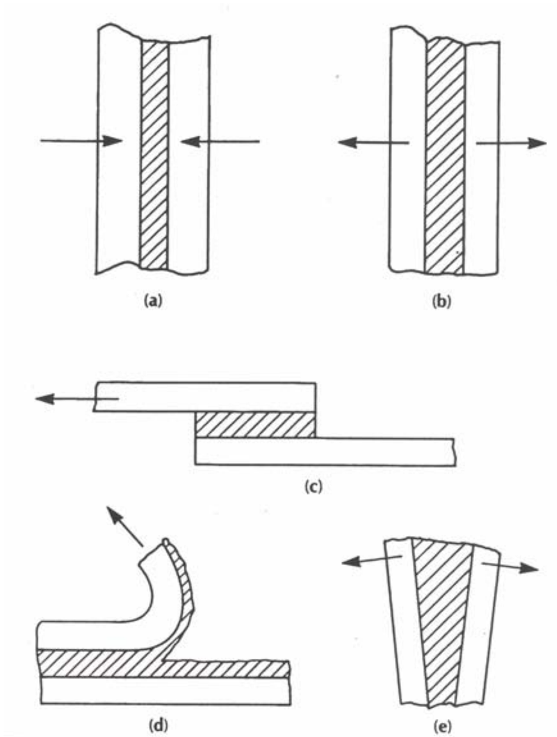


Advanced C/C Composite Radiators



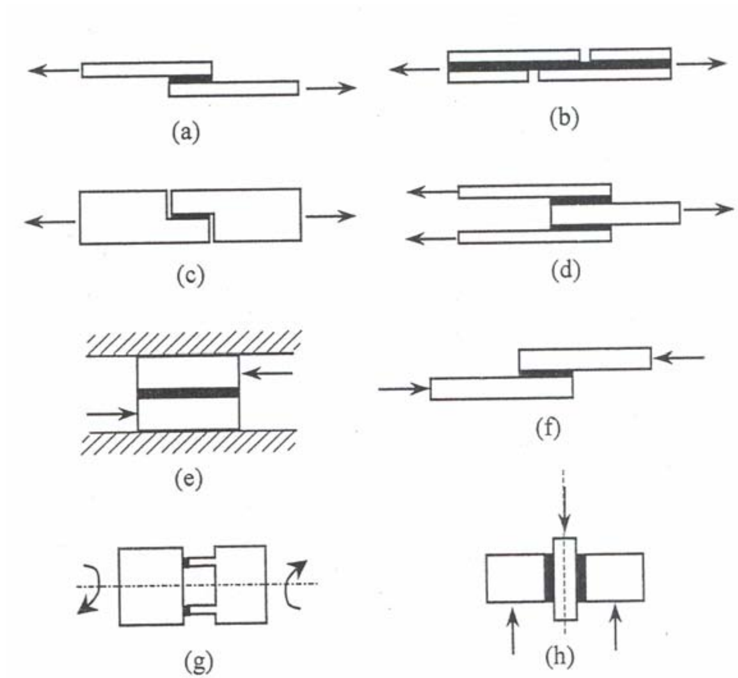
Assembly of Composites with Titanium Tubes

Technical Challenges in Design and Selection of Joints



(a) Compression; (b) Tension; (c) Shear; (d) Peel; (e) Cleavage

Typical Joints will have Combination of Stresses Under Operating Conditions



Different Types of Shear Tests

Various Activities on Bonding of Metals to Ceramics and Composites Using Metallic Interlayers at GRC

Metallic Systems:
- Titanium
- Inconel and Other Ni-Base Superalloys
- Kovar
- Stainless Steels

Active Metal Brazing
Soldering

Ceramics/Composite Systems:
- SiC, Si3N4
- YSZ, Alumina
- C/C Composites
- C/SiC, SiC/SiC

Interlayer Systems:
- Active Metal Brazes (Ag, Cu, and Pd based)
- Metallic Glass Ribbons
- Solders (Zinc based)

Technical Issues:
- **Melting range / behavior**
- **Wetting characteristics**
- **Flux or atmosphere compatibility**
- **Compositional compatibility**
- **Cost & availability**

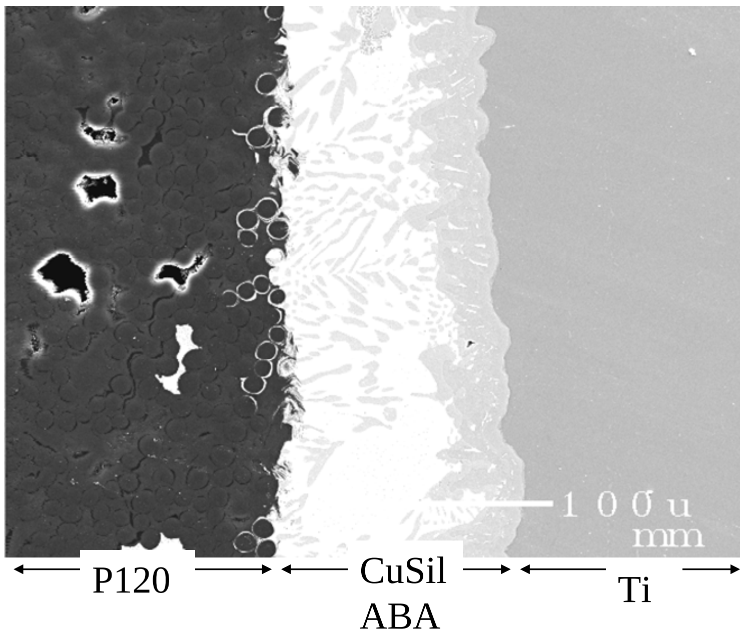
Materials and Experimental Details

- **Titanium (CP-2) plates:** TIMET Corp., MO
- **CVI C/C composites** *(P-120 Fibers, 3 HS, large tow size, 1.2 mm thick)*
  - Goodrich Corp., Santa Fe Springs, CA
- **CVI C/SiC Composites** *(T-300 Fibers, 1K tow, PW, 3.2 mm thick)*
  - GE Power Systems Composites, Newark, DE
- **MI SiC/SiC Composites** *(Sylramic Fibers, 800 fiber tow, 5 HS, 2 mm thick)*
  - GE Power Systems Composites, Newark, DE
- **Polished vs unpolished composite surfaces**
- **Microstructural Analysis** *(Optical, SEM, EDS)*
- **Mechanical Testing:**
  - Microhardness behavior across the joint interface
    - **(Knoop hardness, load: 200 g, loading time: 10 s)**
  - Butt Strap Tension (BST) Shear Tests

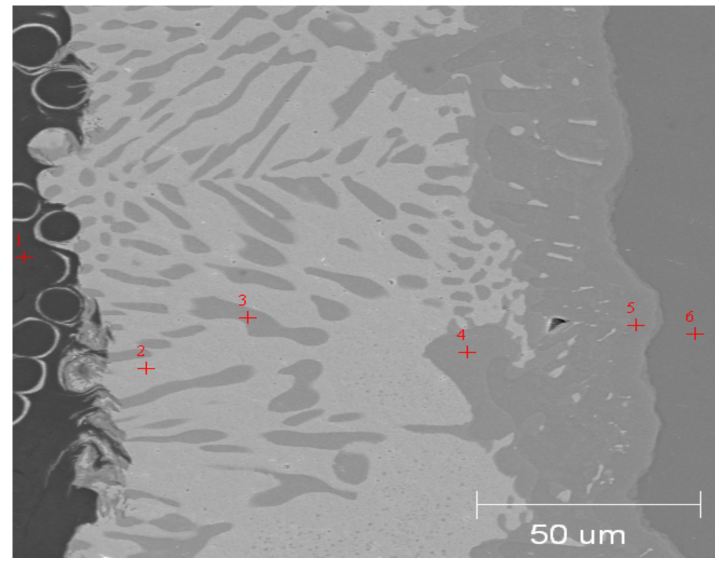
CuSil-ABA braze foil and paste

T_L, °C	T_S, °C	E, GPa	YS, MPa	UTS, MPa	CTE, C^{-1}	% El.	K, W/m.K
815	780	83	271	346	18.5×10^{-6}	42	180

Microstructure of Brazed Ti Plates to C-C Composites using CuSil-ABA Paste



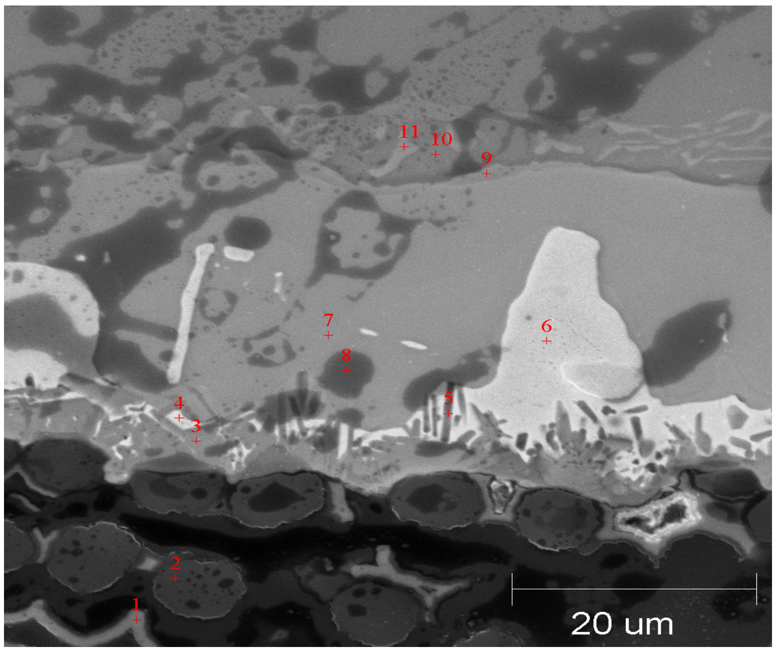
a



b

EDS analysis of compositions at marked locations in (b) : 1) 100%C, 2) 1%Ti, 3%Cu, 96%Ag, 3) 1%Ti, 95%Cu, 4%Ag, 4) 15%Ti, 80%Cu, 4%Ag, 5) 43%Ti, 54%Cu, 3%Ag, and 6) 99%Ti, 1%Ag.

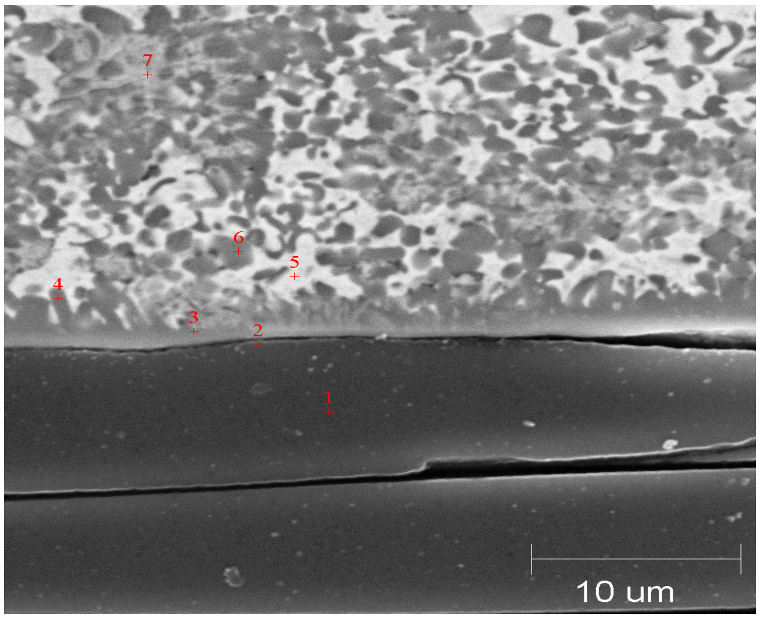
Microstructure and EDS Analysis of C-SiC/Cusil-ABA/Ti joints from braze paste



Braze foil (polished C-SiC)

Location	Si, at%	Ti, at%	Cu, at%	Ag, at%
Point 1	93.892	0.282	2.049	3.778
Point 2	61.302	7.573	14.349	16.776
Point 3	0.105	45.637	49.164	5.094
Point 4	0.291	10.060	34.858	54.791
Point 5	3.249	17.330	4.842	74.578
Point 6	0.661	1.043	2.846	95.450
Point 7	0.175	31.059	66.529	2.237
Point 8	0.442	28.763	68.111	2.684
Point 9	0.384	60.193	36.909	2.514
Point 10	0.248	93.601	5.256	0.895
Point 11	0.045	85.400	13.774	0.781

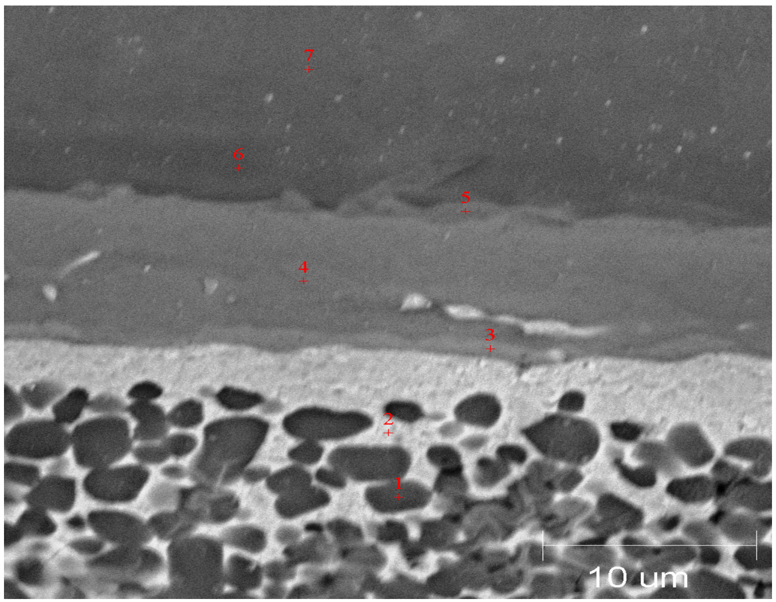
Microstructure and EDS Analysis of C-SiC/Cusil-ABA/Ti joints from braze paste



Braze paste (polished C-SiC)

Location	Si, at%	Ti, at%	Cu, at%	Ag, at%
Point 1	91.962	2.614	1.068	4.356
Point 2	52.058	37.527	5.401	5.014
Point 3	13.867	68.756	11.784	5.593
Point 4	11.558	37.308	1.549	49.584
Point 5	0.994	4.871	1.424	92.712
Point 6	17.754	51.475	8.891	21.880
Point 7	2.469	6.935	86.969	3.627

Microstructure and EDS Analysis of SiC-SiC/Cusil-ABA/Ti joints from braze paste (Ti-Side)

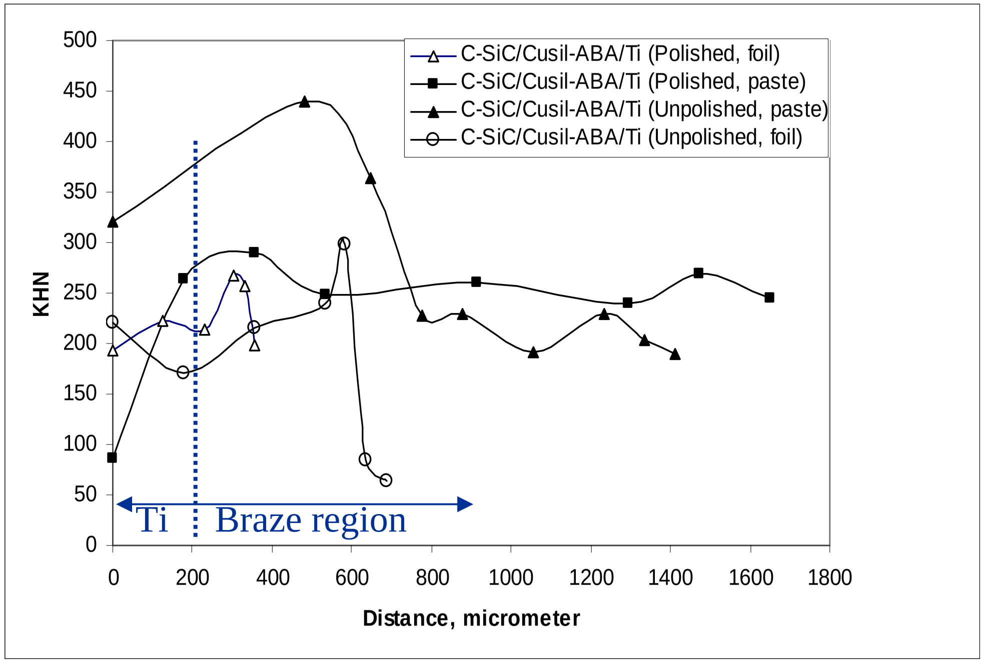


Paste, polished SiC-SiC

Location	Si, at%	Ti, at%	Cu, at%	Ag, at%
Point 1	18.029	60.288	2.361	19.323
Point 2	0.843	3.229	2.038	93.891
Point 3	1.112	16.114	70.797	11.977
Point 4	0.277	35.785	59.986	3.952
Point 5	0.421	63.491	33.433	2.656
Point 6	0.185	97.555	1.422	0.838
Point 7	0.382	98.170	1.035	0.413

Microhardness Profiles across the Joint Region in Brazed C-SiC/Ti System

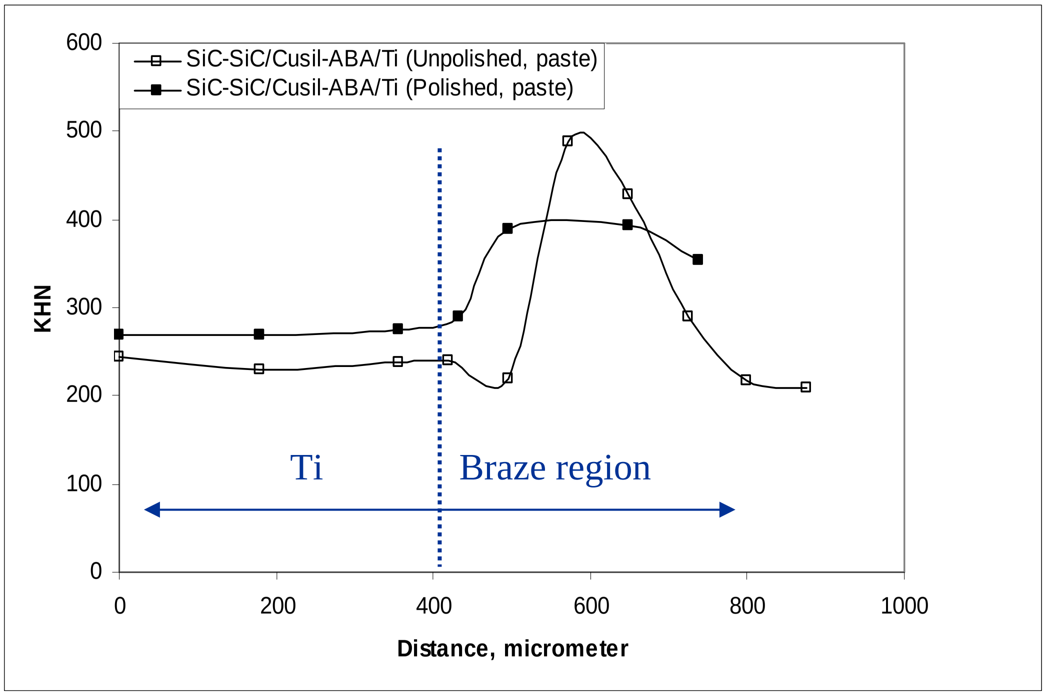
(Knoop indenter, 200 g load, 10 s loading time)



- **Braze/Ti interface was diffuse and its location shown is approximate.**
- **Braze region shows significant variation in KHN than Ti region.**
- **Joints made from unpolished composites show marginally higher peak KHN values than polished samples.**

Microhardness Profiles across the Joint Region in Brazed SiC-SiC/Ti System

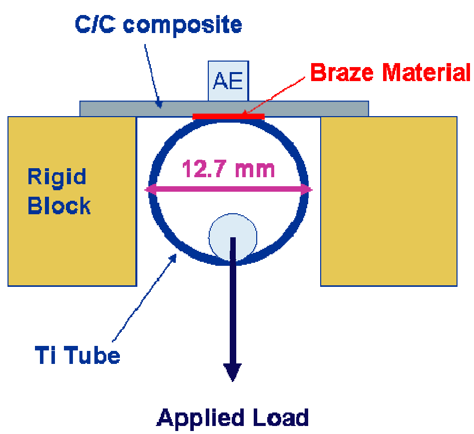
(Knoop indenter, 200 g load, 10 s loading time)



- Braze/Ti interface was diffuse and its location shown is approximate.
- Braze region shows significant variation in KHN than Ti region.
- Joints made from unpolished composites show marginally higher peak KHN values than polished samples.

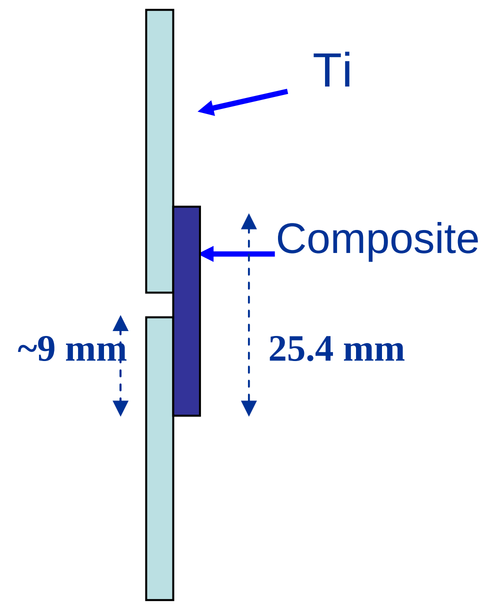
Mechanical Testing of Brazed Joints

Tube Tensile Test



Test data on a wide variety of brazes reported in Mater. Sci. Engg. A, 412 (2005) 123-128 and Mater. Sci. Engg. A., 418 (2006) 19-24.

Butt Strap Tensile Test



Factors to consider:

-Substrate composition, Processing variables

-Bonded area, Location of failure

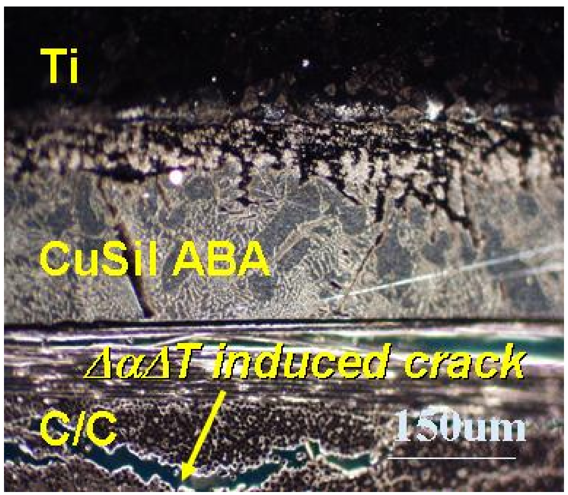
-Architecture effects

BST Shear Strength of Brazed Ti-Composite Joints at Room Temperatures

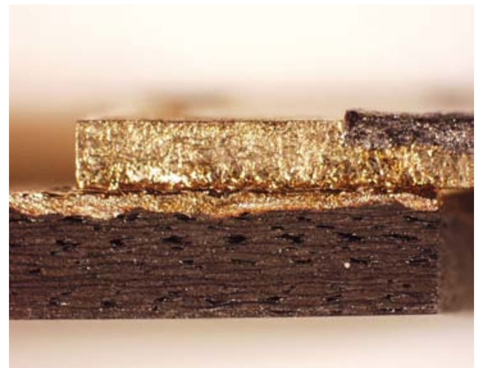
Composite	Surface Condition	Number of Specimens	Shear Strength, MPa
C-C	As-processed	6	1.51 ± 0.76
C-SiC	As-processed	2	$1.78 \pm .09$
C-SiC	Ground	6	1.46 ± 0.56
SiC-SiC	As-processed	4	5.30 ± 1.62
SiC-SiC	Ground	3	9.05 ± 0.55

Typical literature values for interlaminar shear strengh (ILS) of composites: C/C: 12-15 MPa; CVI C/SiC: 18-22 MPa; MI SiC/SiC: 40-45 MPa

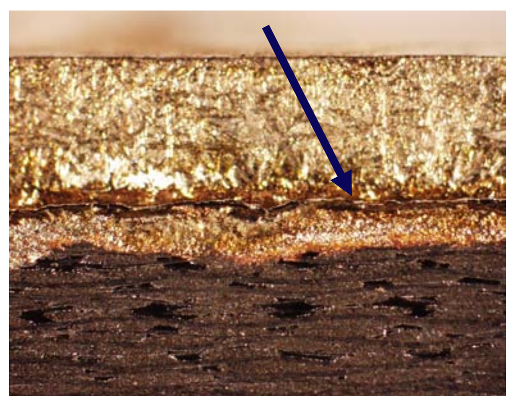
Thermally-Induced Cracking in Composite Controls Shear Strength of Brazed Joints



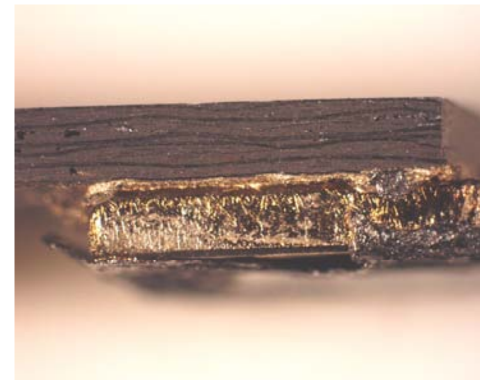
Ti-C/C Composite



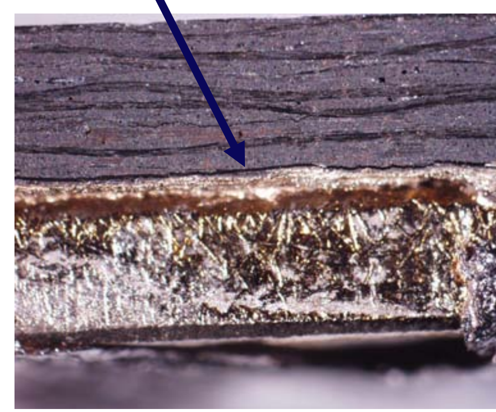
Crack in outer
ply of C/SiC



Ti-C/SiC Composite

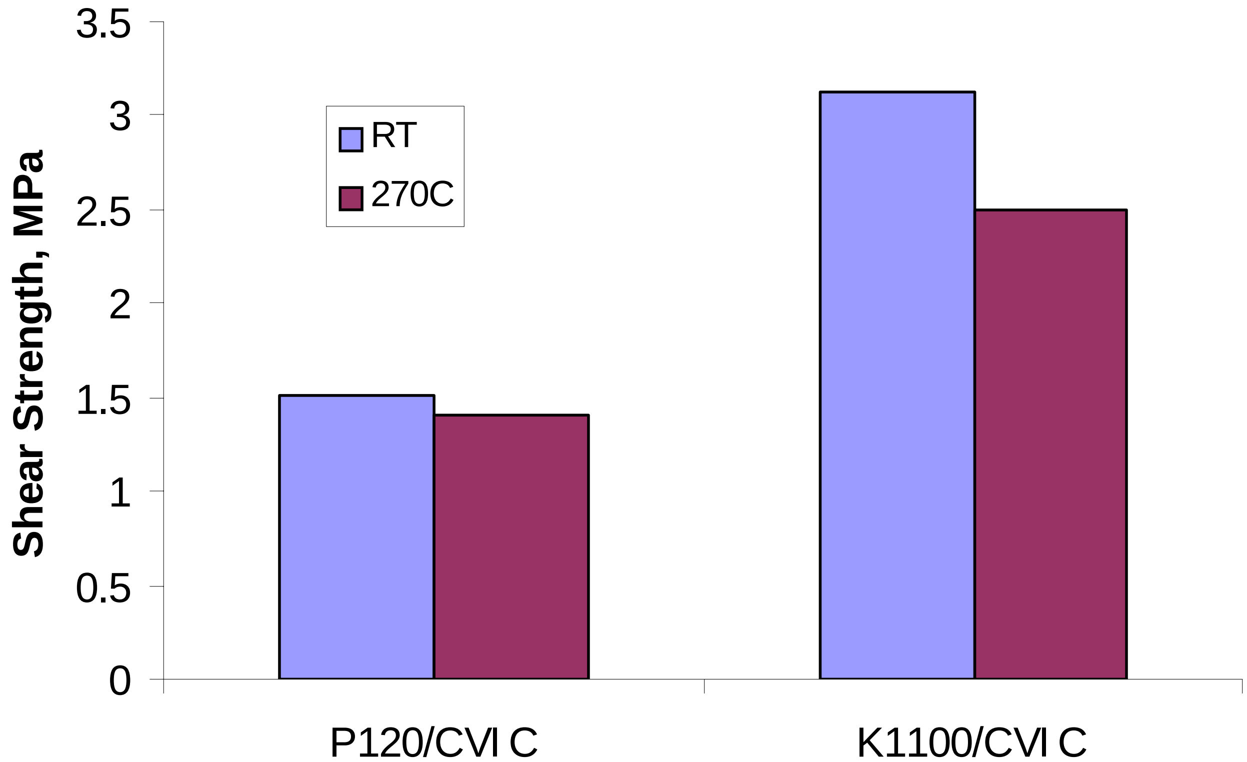


Crack in outer
ply of SiC/SiC



Ti-SiC/SiC Composite

BST Shear Strengths of Brazed Joints in Ti- C/C Composites (woven) with P120 and K1100 Fibers



- High temperature testing of joints with C/SiC and SiC/SiC composite substrates in progress.

Summary and Conclusions

- Cusil-ABA foil and paste can be used to vacuum braze C-C, C-SiC, and SiC-SiC composites to Ti.
- Joint interfaces were defect free and exhibited sound metallurgical bonding in all the systems.
- EDS analysis of the joints in all composites show interfaces enriched in Si and Ti.
- The room-temperature BST tests revealed a higher shear strength in Ti/SiC-SiC joints made using polished composite specimens than as-fabricated specimens.
- Knoop hardness in the braze region was greater than in Ti and showed variation with distance due to residual stresses. The peak hardness in the joint region was marginally higher in unpolished samples.